Space

2024

Thank you to our chapter sponsor:

Introducing the Sun

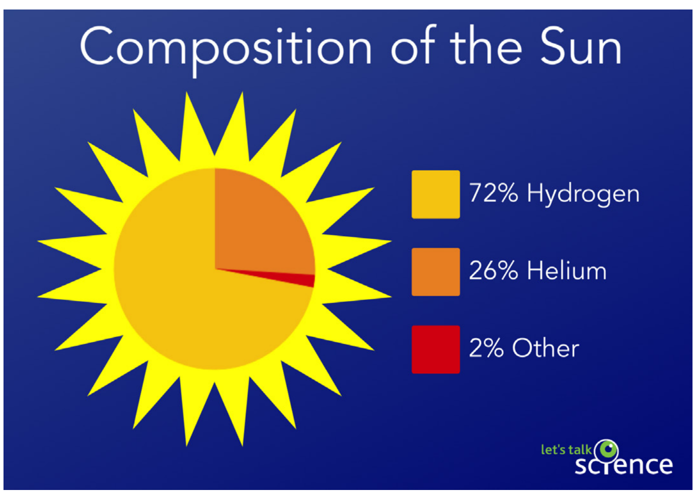
Can you see stars during the day? Yes, you can! Our Sun is a star! From morning until evening you can see the Sun in the sky. The Sun is one of 200 billion trillion stars in the universe.The Sun is the closest star to Earth. In fact, our entire solar system revolves around the Sun.

What is the Sun?

To find out what the Sun is, first we must find out what a star is! Stars are formed from clouds of gases and dust. These clouds are scattered throughout most **galaxies**. Sometimes materials in the clouds clump together. This begins to create **gravity** that pulls in even more materials. The force of the gravity causes the materials to heat up. Eventually the centre, or core, gets hot enough for **nuclear fusion** to take place. At this point, a star is born.

What is the Sun made of?

The Sun isn't solid and rocky like Earth. Instead, it is a massive glowing sphere of hot gases. It's mostly made of the **chemical elements** hydrogen and helium. A small percentage of the Sun is made of carbon, nitrogen and oxygen. There are also small amounts of iron, nickel and other elements.

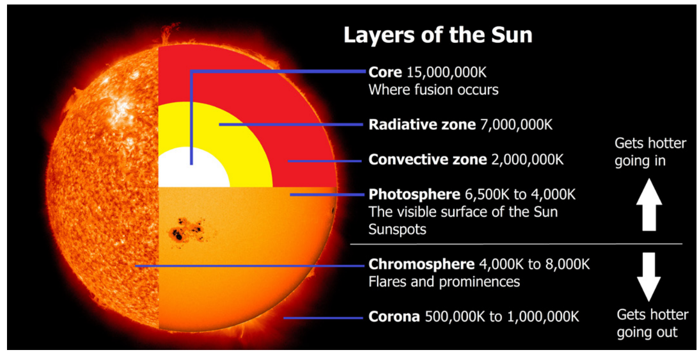


Gases that make up the Sun (©2023 Let's Talk Science).

Parts of the Sun

The Sun is made of many different layers. These layers can be broken down into two sections:

1. Inner Layers
2. Outer Layers



The layers of the Sun (Let's Talk Science using a public domain image by NASA via Wikimedia Commons).

Inner Layers

Core
This is the hottest and **densest** part of the Sun. In this region, hydrogen transforms into helium through nuclear fusion. This process generates bundles of light energy we call **photons**.

Radiative Zone
This region is less dense than the core. Here energy moves from the core outwards.

Convection Zone
In this region, energy moves from the inner layer to the outer layer.

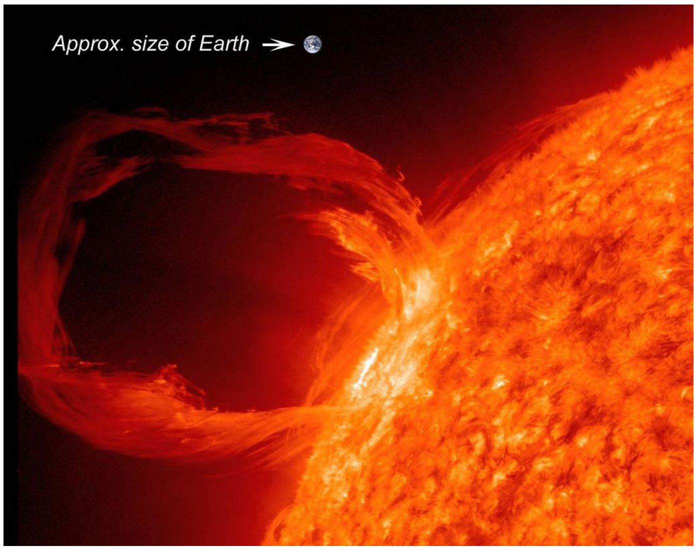
Outer Layers

The outer layers make up the Sun's atmosphere. Energy **radiates** into space from these regions.

Photosphere
This is the part that we refer to as the surface of the Sun. This layer is the source of all **solar energy** that reaches the Earth. The name of this region comes from ancient Greek words "photos" meaning light and "sphaira" meaning sphere.

Chromosphere

The name of this region comes from ancient Greek words “chromo” meaning colour and “sphaira” meaning sphere. This layer looks reddish because it gives off a type of **electromagnetic radiation** in the red part of the spectrum. **Solar prominences** and **solar filaments** are formed in this region.



Solar prominence (Source: Public domain image from NASA).

Corona

This is the Sun’s The Sun's outermost layer. This layer usually is outshone by the other layers of the Sun. However, the corona can be viewed during a total solar eclipse.The corona is the hottest part of the outer layers. Why is this layer so hot? The NASA Parker Probe was sent to the Sun to find out.

How old is the Sun?

A star’s life cycle is closely connected to its size. Small red dwarf stars have fusion that takes place very slowly. These stars can exist for trillions of years. Eventually, they collapse to form **white dwarfs**. Over time, these cool to form **black dwarfs**.

Mid-sized stars, like our Sun, begin to change as they use up their hydrogen. They contract and heat up, becoming **red giants**. As red giants cool, they give off layers of glowing gas we call **planetary nebulas**. They too eventually become white dwarfs.

For the largest stars, their life cycles end with a dazzling explosion known as a **supernova**. These events release huge amounts of energy, and trigger the formation of heavier chemical elements, like gold. After a supernova, the core can become either a neutron star or a stellar black hole.

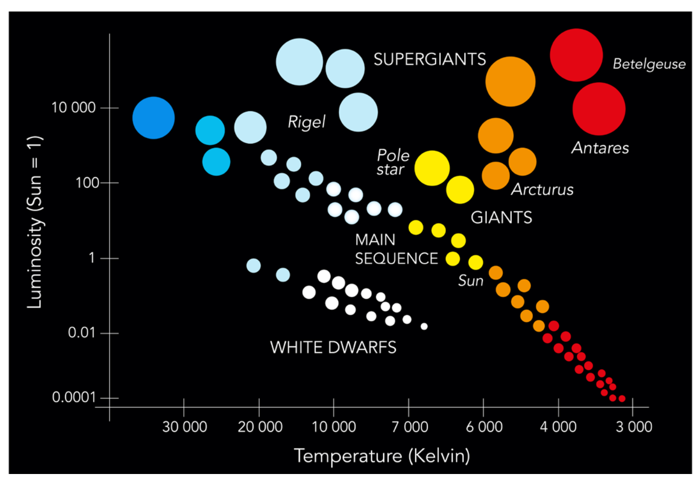
Neutron stars are the smallest and most dense types of stars. The average radius of a neutron star is only 10 kilometres! A **stellar black hole** has gravity that is so strong that even light cannot escape. Scientists usually detect black holes by noticing how gases from nearby stars are pulled into them.

Our Sun is approximately 4.5 billion years old, which makes it a fairly young star. The Universe itself is estimated to be at least 13.7 billion years old. But scientists at the University of Ottawa think that the Universe might be as much as 26.7 billion years old. Most stars have a lifespan of about nine or 10 billion years, making our Sun a middle-aged star.

Did you know?
The oldest star known is called Earendel. It is a star in the constellation of Cetus. It is estimated to have been formed around 900 million years after the Big Bang.

How big is the Sun?

The Sun is part of a group of stars we call G-type main-sequence stars, or yellow dwarfs. The stars in this group come in a wide range of sizes and **luminosity** (brightness). They range from one-tenth to 200 times the Sun's mass.



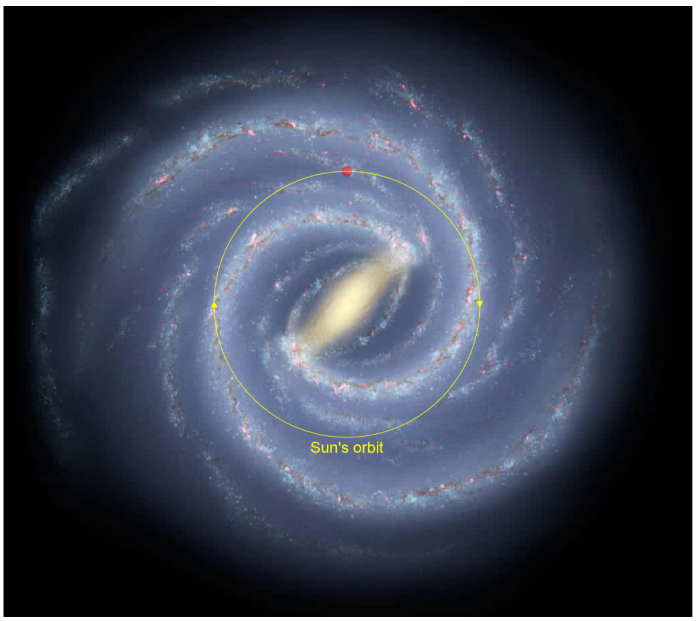
Main sequence stars, including the Sun (Source: gstraub via Getty Images).

The Sun has a diameter of 1.4 million kilometres (865,000 miles). Its diameter is about 109 times the diameter of the Earth. It would take more than one million Earths to fill the Sun's entire volume.

Where is the Sun located?

The Sun is found in the Orion Spur of the **Milky Way Galaxy**. The spur juts off the Sagittarius arm, which is one of the spirals that make up the galaxy.

The Sun follows a clockwise orbit around the centre of the galaxy, which is between 24 000 and 26 000 **light years** away. This orbit takes roughly 225 to 250 million years to complete.



Gases that make up the Sun (©2023 Let's Talk Science).

The Sun is at the centre of our **Solar System**. It is approximately 150 million kilometres (93 million miles) from Earth. This location, which is neither too close to, nor too far from the Sun, allows life to occur on Earth.

What does the Sun do for the Earth?

The Sun is extremely important for life on the Earth. It provides light and heat for plants and animals, including humans. The Sun's light enables plants to store energy through **photosynthesis**. Humans and other animals rely on these plants for food. Because of its distance from the Sun, Earth is able to have liquid water. If it was too far from the Sun, the water would be all frozen. If it was too close, the water would all evaporate. Water is essential for most living things on Earth.

The sun also has other important influences on our planet. It is the driving force of our weather patterns, **ocean currents**, **seasons** and **climate**. Without the Sun, life on Earth would not be possible as we know it.

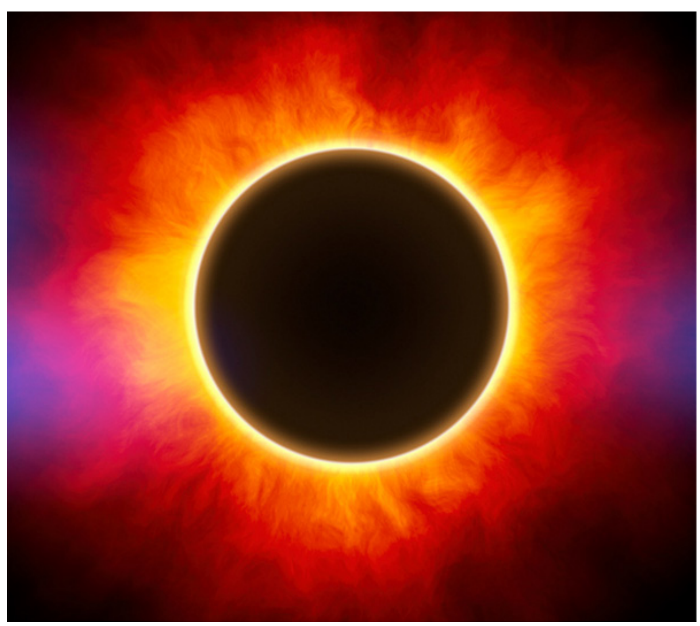
Why do we call it the "Sun"?

The word "Sun" comes from the latin word "sol." This word is used as the main adjective for many Sun-related terms in English, such as solar. Many cultural communities have their own word for the Sun.

The Sun has played an important role in different communities across the world over time. In ancient Greek myths, Helios is the Sun god. This name is also used in many Sun-related terms, like heliosphere and helioseismology.

Inti, also called Apu-punchau, is the Sun god from ancient Inca mythology. Ancient Mayan mythology features a Sun god called Kinich Ahau. Amaterasu Ōmikami is the celestial Sun goddess in the Shinto faith. Each of these deities has a detailed narrative, and is important in their respective culture.

Above the Arctic circle, some Inuit, Yupik, Aleut, Chukchi and Iñupiat people observe the first sunrise on the first day of the year (Inuktitut: ᓯᕗᓪᓕᖅᐹᖅ ᓯᖅᑭᓂᖅᓄᐃᐊᖅ) by extinguishing three qulliqs (traditional oil lamps) and relighting them. This ritual celebrates the story of both Sun and her brother Moon, who are known by several different names across the circumpolar world.



Solar corona (Source: dem10, Getty Images).

The Magnetic Sun

Did you know that the Sun, like Earth, has a magnetic field? This field affects our planet and our solar system! Let's learn more about how it works.

What is a magnetic field?

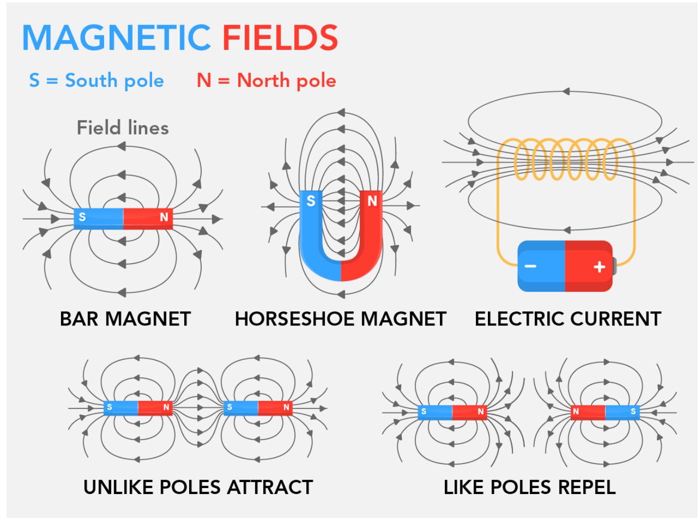
Some materials can produce a **magnetic field**. We call objects made from these materials **magnets**. **Permanent magnets** create and maintain their own magnetic fields. A fridge magnet is an example of a permanent magnet. Other objects only have the properties of a magnet temporarily. They get these by being **magnetized**.

Magnetism is a force exerted by magnets when they attract or repel each other. This force is caused by the movement of **charged particles**. Because of this movement, every atom acts like a tiny magnet. In most materials, equal numbers of electrons spin in opposite directions. This cancels out their magnetism. But in strongly magnetic materials, like **iron**, **nickel**, **cobalt** and **steel**, the electrons all spin in the same direction.

> Did you know?
> Strongly magnetic materials can become magnetized by entering the magnetic field of a magnet.

Magnets have two ends, called **poles**. One is called the **north pole** and the other the **south pole**. Opposite poles (north and south) **attract** each other. Same poles (north and north, or south and south) **repel** each other. This helps explain why magnets can pull together or push apart.

We cannot see magnetic fields with our eyes, but we can visualize them using iron filings and a bar magnet. The pattern that the filings make are magnetic field lines. Magnetic field lines are close together where the magnetic force is strong. They are further apart where the magnetic force is weak. The density of the field lines indicates the strength of the field.



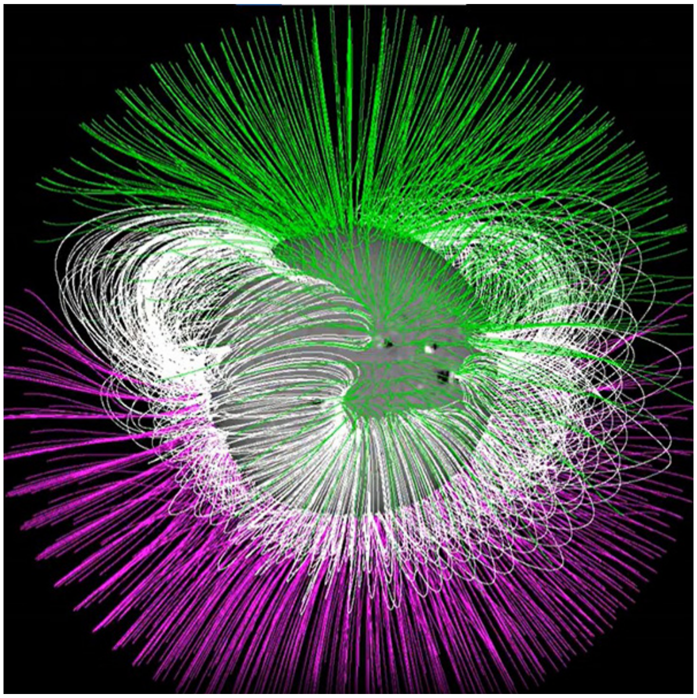
Examples of various patterns of magnetic field lines (©2023 Let's Talk Science using an image by anuwat meereewee via Getty Images).

The Sun's Magnetic Field

The Sun's core is exposed to massive amounts of **pressure** from the outer layers of the Sun. This pressure strips **electrons** from hydrogen **atoms**. This mixture of positively charged atomic nuclei and negatively charged electrons is what scientists call **plasma**. The movement of these electrons in the Sun's plasma creates a complex and dynamic magnetic field. This extends throughout the Solar System.

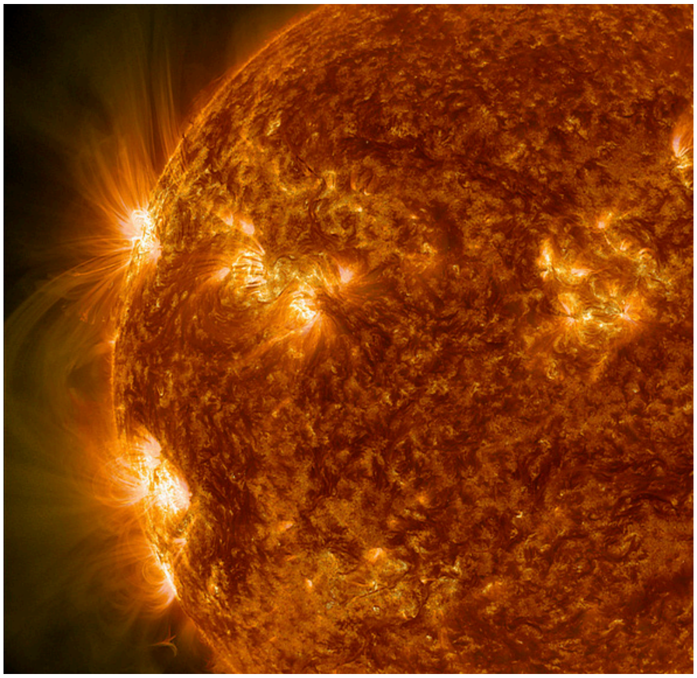
> Did you know?
> Plasma is a **state of matter**.

Scientists have tried to understand the Sun's magnetic field using computer models. The image on the next page was created using the Potential Field Source Surface (PFSS) model. The white lines represent closed field lines. These start and end at the Sun. Green represents positive open field lines and purple represents negative open field lines. Open field lines do not connect back to the Sun. They connect with other magnetic fields in space.



Sun magnetic field lines (Source: screen capture, NASA)

Magnetic field lines can cross and suddenly snap. This can send nearby particles off into space at great speeds. This is called **magnetic reconnection**. It's a lot like when a rubber band is stretched out and released. Magnetic reconnection plays an important role in events like solar flares and **coronal mass ejections**. In the image on below, there is a magnetic reconnection between the two bright areas in the image below.



Magnetic reconnection on the Sun (Source: Stocktrek Images via Getty Images).

The Sun's Corona

Most electromagnetic field activity takes place on the Sun's **corona**. The corona is the outermost layer of the sun. The activity we can see includes **sunspots**, **solar flares**, **solar wind** and **coronal mass ejections**. These events are sometimes referred to as **solar storms**. They influence **space weather**, which impacts Earth's magnetic field.

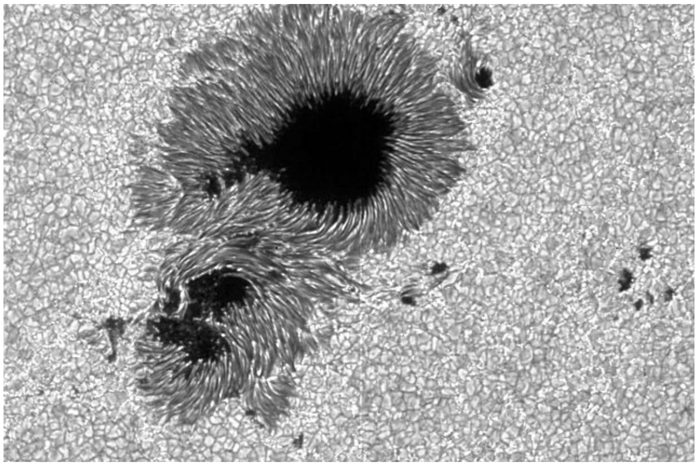
Did you know?
The corona is much hotter than the Sun's surface. The corona is about 1 million °C and the surface is about 5 500 °C!

Sunspots

A very noticeable feature of the Sun are sunspots. **Sunspots** look like dark blotches on the surface of the Sun. The "spots" are planet-sized areas where the magnetic field is very strong. They look darker because they are cooler than their surroundings. But they are still quite hot! The surface of the Sun is about 5 500 degrees Celsius. A sunspot is about 3 200 degrees Celsius.

Sunspots have two main parts.

1. The **umbra** is the darkest part of a sunspot. This is where the magnetic field is very strong. It points straight up from the Sun's surface.
2. The **penumbra** is the less dark area surrounding the umbra. It has stretched structures called penumbral filaments. These look like they are reaching out from the umbra.



Two sunspots with umbras and penumbras (Source: Public domain image by NASA via Wikimedia Commons).

The Solar Cycle

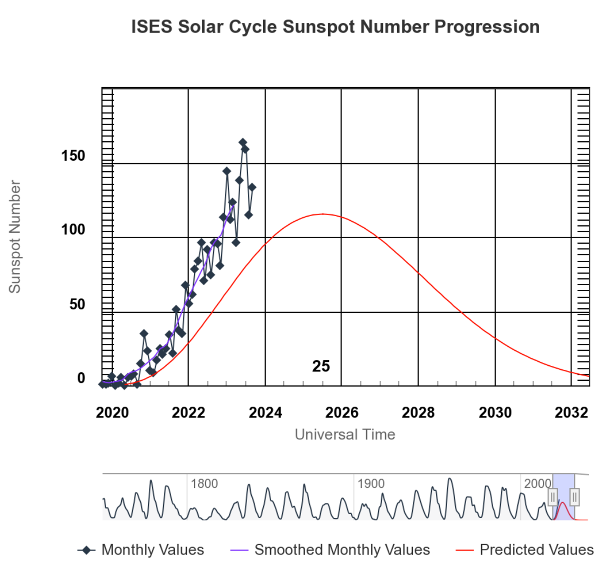
The **solar cycle**, also known as the **solar magnetic activity cycle**, **sunspot cycle**, or **Schwabe cycle**, is the cycle of activity the sun goes through about every 11 years. This activity is measured in the number of sunspots.

During a solar cycle, the Sun's behaviour follows a known pattern. It starts with low activity, then goes to high activity, and back to low activity again. Like sunspots, the number of solar flares also follows the solar cycle.

The magnetic field of the Sun flips once during each solar cycle. This means that the north pole becomes the south pole and the south pole becomes the north pole. The flip happens when the solar cycle is near the **solar maximum**. This is the time when there is the greatest amount of solar activity.

After two solar cycles, the Sun's magnetic field returns to its original state. At this point, it has completed a **Hale cycle**. By keeping track of the number of sunspots, scientists know where the Sun is in the cycle.

As of 2023, the Sun is in Solar Cycle 25. This means it is the 25th cycle since the first recording of sunspot activity in 1755.



Number of sunspots observed between 2020 and 2023 (Source: Public domain image by the NOAA via Wikimedia Commons).

With solar activity on the rise, don't be surprised if you start hearing more about our amazing magnetic Sun!

Solar Storms: Exploring the Sun's Explosive Outbursts

Did you know that space experiences weather? This is known as **space weather**. Earth's weather involves conditions like temperature and humidity. Space weather involves **radiation**, charged particles and solar wind. These cause powerful storms. The storms are called **solar storms** or space weather storms.

Solar storms release bursts of high-energy particles and **electromagnetic radiation**. These can create colourful patterns in the sky above Earth. They can also impact satellites. In this backgrounder, we'll explore the science of solar storms, their causes, and how scientists predict and understand space weather.

What is a solar storm?

A solar storm is a disturbance on the surface of the Sun. These storms can take the form of large explosions called solar flares. Or they can be bursts of **plasma** called coronal mass ejections, or CMEs.

Let's take a closer look at these two types of storms.

Types of Solar Storms

Solar Flares

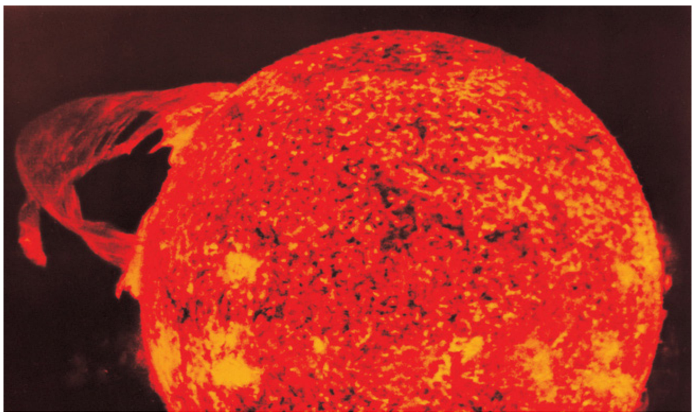
Solar flares are like fireworks from the Sun. They are massive explosions of electromagnetic radiation that happen on the Sun's surface. The surface of the Sun is covered in a web of magnetic fields. Sometimes these **magnetic fields** can get twisted and tangled up, like rubber bands wound too tightly. When this magnetic tension builds up, it can suddenly untangle. This releases a burst of energy in the form of a **solar flare**.

The radiation released in solar flares can range across the electromagnetic spectrum from radio waves to x-rays and gamma rays. These can look like a sudden, intense burst of light and last for a few minutes, or even hours.

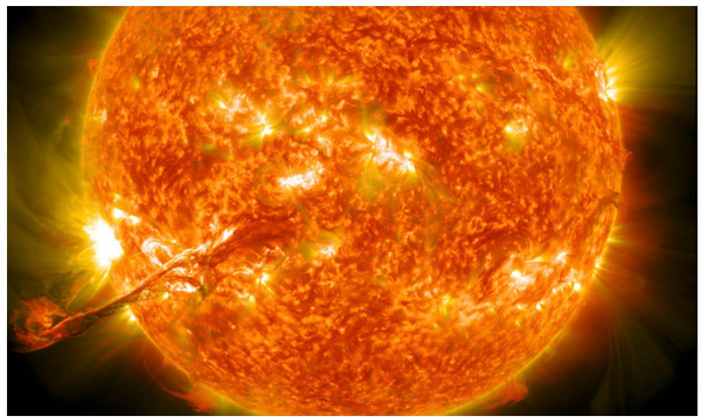
Types of Solar Flares

Scientists classify solar flares into four categories. These are based on their x-ray brightness. The categories are: X-class, M-class, C-class and B-class. Each category has its own characteristics and effects on Earth.

Category	Effects
B-Class: Very Small Ones	• Its radiation is not detectable from Earth • There are no detectable effects on Earth
C-Class: Small Ones	• There is a minor release of radiation • They don't usually cause effects on Earth
M-Class: Medium-Sized Ones	• There is a significant release of radiation • They can trigger brief radio blackouts, minor disruption of satellites and auroras
X-Class: Big Ones	• These are major events that release a tremendous amount of radiation • They can have a big impact on earth. They can trigger global radio blackouts amd disruption of satellites



Solar flares on the surface of the Sun (Source: Digital Vision via Getty Images).



Large coronal mass ejection erupts on the Sun (Source: Stocktrek Images via Getty Images).

Coronal Mass Ejections (CMEs)

Coronal Mass Ejections are not your everyday solar events. They are massive expulsions of plasma and magnetic fields that shoot out from the **Sun's corona**.

CMEs occur because of disturbances in the Sun's magnetic field. Most CMEs form near **sunspots**, which are cooler and darker areas on the Sun's surface.

CMEs travel out from the Sun at very high speeds. The slowest CME's are less than 250 kilometres per second (km/s). The fastest are nearly 3 000 km/s. This means that the fastest CMEs can reach Earth in just 15-18 hours!

CMEs are so intense that they can pose some serious challenges for space activities. The radiation storms within CMEs can be hazardous to spacecraft and astronauts.

Did you know?
In 2022, NASA's Parker Solar Probe became the first spacecraft to fly through a Coronal Mass Ejection (CME). Parker was about to make its 13th close approach to the Sun when a CME erupted right in front of it.

How do solar storms impact Earth?

So why don't we feel the direct impact of solar storms? Earth's **magnetic field** protects us from their harmful effects. The magnetic field creates a protective bubble around the planet we call the magnetosphere. It deflects and redirects harmful particles away from the Earth.

Did you know?
Scientists can recreate the protection of the earth's magnetic field by making a Faraday cage. These are protective enclosures that prevent electromagnetic radiation from entering them.

Even though we don't get hit with the full impact of solar storms, they are still noticeable. When solar storms interact with the Earth's magnetic field, it can cause disturbances in the field. Scientists call these **Geomagnetic storms**.

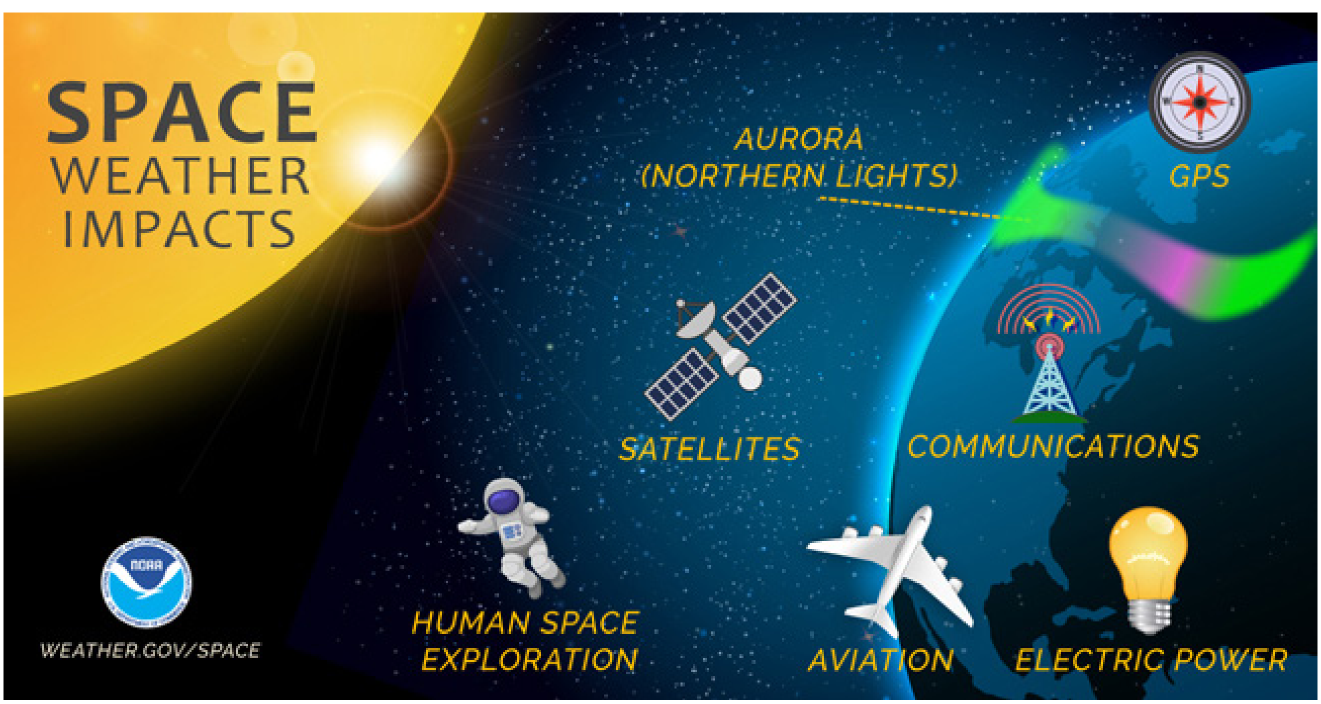
Geomagnetic storms can affect our planet in some fascinating and challenging ways. For example, when a CME collides with Earth's magnetic shield, the impact can send a burst of particle radiation into Earth's upper **atmosphere.** If the particles interact with the gas molecules in Earth's **thermosphere**, they can light up. These excited gas molecules create mesmerising light shows we call auroras.

Impacts on Technology

Geomagnetic storms can impact technology, like Earth's communication systems. You might have experienced static or interference on your radio during a thunderstorm.

In a similar way, the increased electromagnetic activity during a geomagnetic storm can interfere with r**adio waves**. This interference can disrupt long-distance communication, such as those used in aviation.

Geomagnetic storms also impact **satellites**. Many satellites orbiting the Earth are important for weather forecasting, **global positioning systems (GPS)**, and communication. The increased radiation and charged particles can damage or disrupt satellite



Impacts of space weather (Source: Public domain image by the US National Weather Service).

operations. Scientists use a scale they call the **Geomagnetic Storm G-Scale**, to rank storms. This is based on how disruptive they are. Storms are ranked from G1-G5. G1 storms cause minor disruptions and G5 storms cause severe disruptions.

Predicting solar storms

So how do scientists predict solar storms? The Canadian Space Weather Forecast Centre and the Space Weather Prediction Centre are North American organisations that track, analyze, and forecast space weather. The scientists at these centres use ground-based instruments and satellites to observe the Sun for any changes or activity such as solar flares or CMEs.

Instruments like Nasa's Advanced Composition Explorer (ACE) orbit 1.5 million kilometres above the Earth. It provides important information to scientists who study patterns and clues to generate space weather forecasts.

> Did you know?
> You can check the space weather forecast just like you can check the weather on Earth!

Solar storms are extraordinary space weather events. They can have a big impact on our world. Scientists play an important role by studying the effects of these events and how to predict them.

Global satellite network around the Earth (Source: Mark Garlick/Science Photo Library via Getty Images).

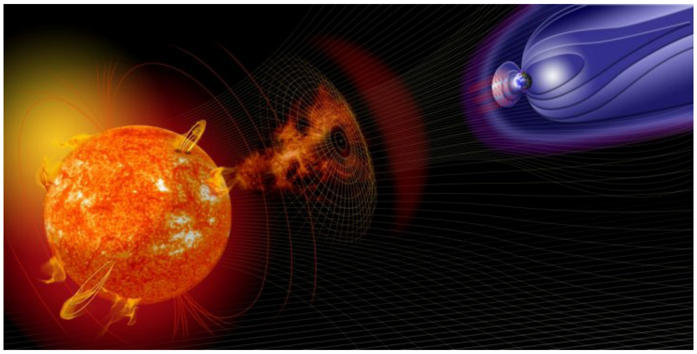
Observing and Predicting Space Weather in Canada

A weather forecast usually provides information about clouds, precipitation or wind. But did you know there's another type of weather forecast? It's called a space weather forecast!

Space Weather: it all starts at the Sun

Space weather is caused by the **Sun**. It blasts charged particles (electrons and protons) out in the **Solar System**. This is called the **solar wind**. Earth's magnetic field forms an invisible shield that redirects the solar wind around our planet. This magnetic bubble is called the **magnetosphere** and is thousands of times larger than our planet!

As Earth's magnetosphere shields us from the solar wind, the magnetic field lines are dragged and stretched by the solar wind. This dragging and stretching causes **electric currents** as charged particles are pushed around Earth's magnetic bubble. When the Sun is more active, it sends out more solar wind that buffets the Earth's magnetic field, which in turn creates stronger electric currents. We call these disturbed conditions **geomagnetic storms** or space weather storms. Let's learn about what these storms do on Earth, and how people are working to forecast them.



Artist illustration of the solar wind stretching Earth's magnetic field (Source: Public domain image by NASA).

Space Weather and the Ionosphere

The **ionosphere** plays a very important part in space weather. In this region (from ~60 km up to a few hundred km) some of the air has been split into electrons and ions. This is how the ionosphere got its name. It is an important region for space weather because the electric currents flowing around the magnetosphere can only connect to one another in the ionosphere through horizontal electric currents. Most of the dangers to humans from space weather are because of these horizontal currents flowing a few hundred kilometres above the surface of the Earth.

> Did you know?
> Auroras happen in the ionosphere when charged particles collide with our atmosphere.

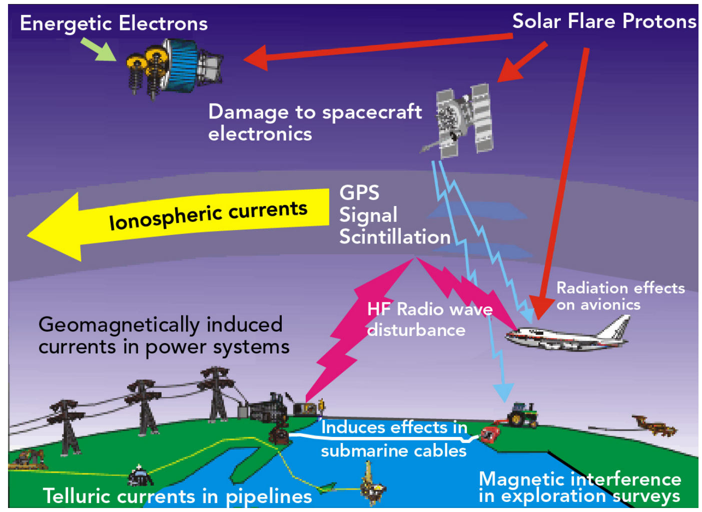
Impacts of Space Weather

In 2012, a powerful **coronal mass ejection** from the Sun just missed Earth. This was observed by a NASA science satellite called STEREO. If Earth had been in a different position in its orbit, it could have caused billions of dollars in damage.

Space weather can affect electrical power on Earth. In 1989, a solar storm knocked out Hydro-Quebec's **electrical grid**. This caused a nine-hour power outage. Solar storms do this by overheating and damaging **transformers**. Transformers increase and decrease the **voltage** in an electrical system. When they fail, electricity cannot flow through the grid.

Space weather can also damage satellites. People rely on satellites for some TV, Internet, and cell phone services. We also need satellites to use the Global Positioning System (GPS). In 1994, solar storms damaged two Canadian communications satellites. As a result, the company lost millions of dollars. Since then, solar storms have damaged many other satellites.

Space weather influences systems connected with Earth's magnetic field. These include surveying and drilling systems that use the Earth's magnetic field to pinpoint locations. During solar storms, these systems become less **accurate**. It can also change the **currents** in long electrical **conductors** like power lines and pipelines. This can make the metal in these objects **corrode** faster.



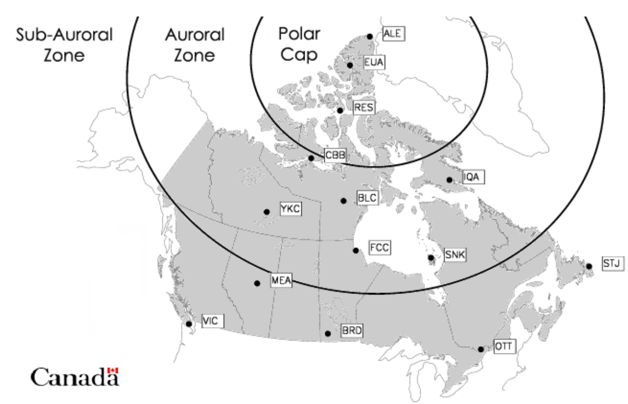
Impacts of space weather (Source: Natural Resources Canada).

Predicting Space Weather in Canada

Like the weather on Earth, space weather can be forecast. The **Canadian Space Agency** and **Natural Resources Canada** are working together to improve space weather forecasting.

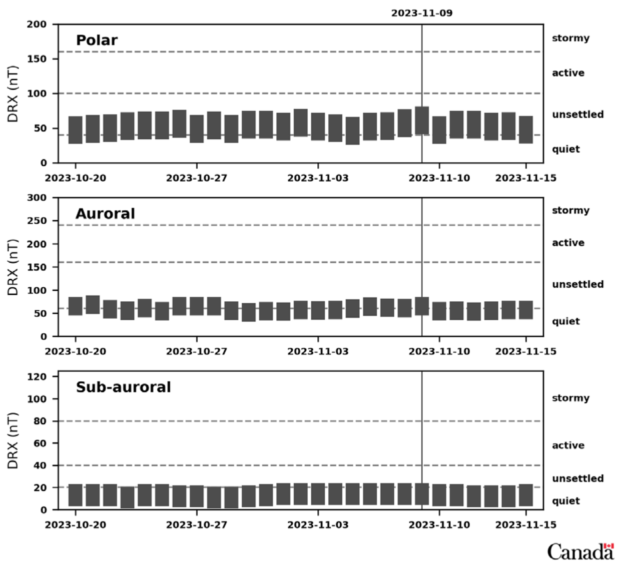
The **Canadian Space Weather Forecast Centre** is a central source of information. Scientists at Canadian universities designed the website and run it. It includes many tools that help scientists predict severe space weather.

One type of information they provide is a **long-range solar forecast**. This is a 27-day forecast of magnetic activity for three regions of Canada. These are the polar cap, the auroral zone and the sub-auroral zone.



Locations of the three regions used for long-range solar forecasts (Source: Natural Resources Canada).

What do you notice when you look at these three graphs?



Locations of the three regions used for long-range solar forecasts (Source: Natural Resources Canada).

People can also access short-range forecasts and reviews. These cover 24 hours in the past and future. Colour-coding helps viewers understand the level of storm activity.

Magnetic Activity Review and Forecast for 2023-11-09 18:45 UT (2023-11-09 13:45 EST)

	Sub-Auroral	Auroral	Polar
24 Hour Review	quiet + unsettled intervals	unsettled + stormy intervals	quiet + unsettled intervals
6 Hour Review	quiet	quiet + active intervals	unsettled
Current Conditions	quiet	quiet	quiet
6 Hour Forecast	quiet	quiet + unsettled intervals	unsettled
24 Hour Forecast	quiet	unsettled + active intervals	quiet + unsettled intervals
Following 24 Hour Forecast	quiet	quiet	unsettled

No storm watch in effect

Locations of the three regions used for long-range solar forecasts (Source: Natural Resources Canada).

These forecasts warn industries that solar storms are on the way. Airlines can change their flight paths, power companies can adjust their grids, and GPS services can issue alerts. Also, operators can put satellites in safe mode or turn off systems that could be damaged.

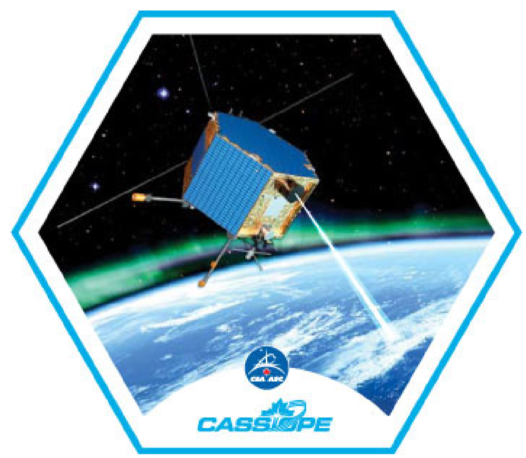
Did you know?
Not all space weather phenomena are caused by the Sun! A volcano on Earth erupted in January 2022. It caused a “super bubble” in the ionosphere. This disrupted satellite navigation systems!

Observing Space Weather in Canada

CASSIOPE

Canada observes space weather with a **satellite** called **CASSIOPE**, or Cascade Smallsat and Ionospheric Polar Explorer. It uses a group of scientific instruments called ePOP to observe the ionosphere.

ePOP stands for enhanced Polar Outflow Probe. This includes eight scientific instruments. There are plasma imagers, radio wave receivers, **magnetometers** and cameras.



CASSIOPE logo (Source: Canadian Space Agency).

Professor Andrew Yau of the University of Calgary directs the ePOP project. His team includes researchers and engineers from seven Canadian universities. The Communications Research Centre Canada, the Institute of Space and Astronautical Science of Japan, and the U.S. Naval Research Laboratory are also partners.

Geospace Observatory Canada

Geospace Observatory Canada supports researchers as they gather space weather data. This data is used to improve space weather reporting. Space weather can be observed and understood in different ways. For example, scientists can combine measurements from space and from Earth.

They can track radio waves to learn how they are absorbed and reflected by space weather. They can also observe the patterns and locations of auroras. By analyzing all this data, researchers can better understand space weather and its effects on Earth.

Two projects funded by Geospace Observatory Canada are the Super Dual Auroral Radar Network (SuperDARN) and Space Environment Canada (SEC).

SuperDARN

SuperDARN is a global network of radar systems developed by the University of Saskatchewan. Scientists use these radars to monitor conditions in the ionosphere and **magnetosphere**. This helps researchers see how space weather conditions affect the flow of charged particles in these regions. SuperDARN operates five radars in Canada. These are in Saskatoon, Prince George, Rankin Inlet, Inuvik, and Clyde River.

SuperDARN radar towers outside of Saskatoon, Saskatchewan (Source: Drm310 [CC BY-SA] via Wikimedia Commons).

Space Environment Canada (SEC)

SEC is a leader in research about the ionosphere. They are a Canada-wide network of over 100 ground-based instruments. These provide researchers with a lot of data! This data is freely available. It is used in Canadian and international space missions.

The SEC is based out of Athabasca University, the University of Alberta and the University of Calgary. The SEC uses magnetometers and the instruments below:

- **All-sky imagers** - specialized cameras that take pictures of the entire sky to study auroras
- **Riometers** - devices that measure the strength of radio signals coming from space to study the properties of the ionosphere
- **Spectrographs** - devices that split light into its individual colours and record their intensities. This helps scientists analyze the chemical composition of objects

Innovative Canadian technologies help advance our understanding of space weather. The more we learn about it, the better we can handle its effects on Earth!

Let’s Talk Science appreciates the support and content validation from the Canadian Space Agency in the development of this part of the handbook.

Different instruments and members of the Space Environment Canada collaboration (Source: Space Environment Canada).

Auroras: Spectacular Light Shows

Aurora borealis near Churchill, Manitoba (Source: Brent Hussin via Getty Images).

Have you ever looked up at night and seen a shimmering curtain of lights in the sky? If so, you're pretty lucky! Auroras are only visible at certain times and places on Earth.

What do auroras look like?

Earth's **atmosphere** contains different types of gases. These gases can emit light when they collide with high-energy particles from the **Sun**. The colour of the light depends on the type of gas. It also depends on the **altitude** at which the collisions occur.

Green is one of the most common colours in auroras. This happens when particles collide with oxygen molecules between 100 and 300 km above Earth. Pink and dark red colours happen when particles collide with nitrogen molecules at about 100 km. Finally, blue and purple are caused by hydrogen and helium. These colours can be hard to see against the dark night sky.

Did you know?
Auroras can be seen from space. Astronauts can get a close up view!

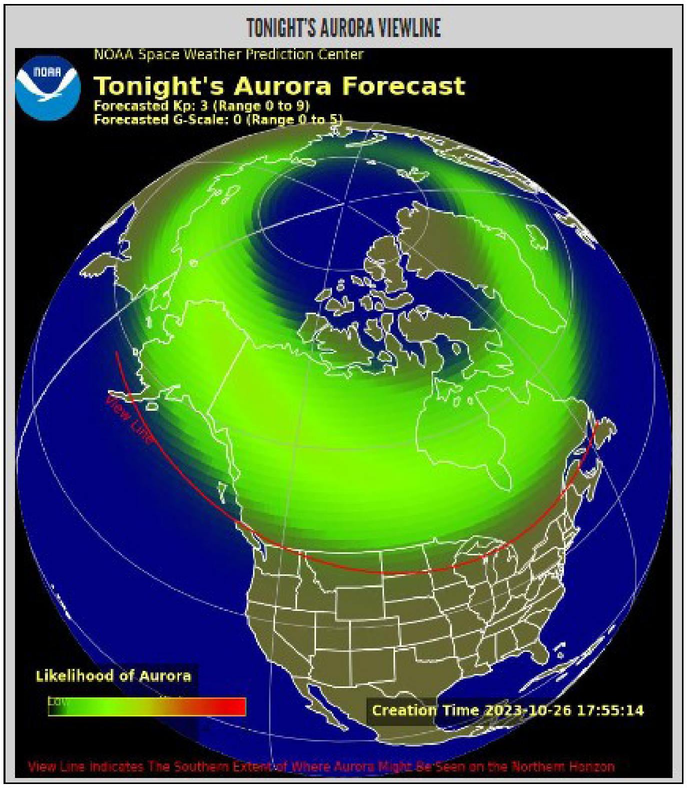
Where can you see auroras?

Auroras are typically seen near the Earth's poles. We call the auroras near the north pole **aurora borealis**, or northern lights. We call the auroras near the south pole **aurora australis**, or southern lights.

Aurora borealis can be seen in northern parts of Earth's northern hemisphere. This area includes parts of Canada, Alaska, Russia, Norway, Finland, Sweden, Iceland and Greenland.

Auroras appear most often between 60 and 75 degrees north **latitude**. In Canada, this includes communities in Yukon, Northwest Territories and Nunavut. But sometimes they can be seen further south, around 50 degrees. Communities near this latitude include Calgary, Regina, Winnipeg, and Happy Valley-Goose Bay.

Try this!
You can check if you're likely to see the northern lights using Natural Resources Canada space weather forecast. The National Oceanic and Atmospheric Administration's Space Weather Prediction Center has forecasts for both the northern and southern lights.



Aurora forecast for October 26, 2023 (Screen capture from Aurora Viewline for tonight and tomorrow (Experimental).

Aurora australis are only visible in a few places on Earth, and some of them are pretty remote. This may be why the southern lights are less well-known. They can be seen from the southernmost parts of Australia and Argentina, as well as New Zealand, South Georgia Island and Antarctica!

> Did you know?
> Historians think the furthest south the northern lights have ever been seen is in Honolulu, Hawaii. That is only 21 degrees north of the equator! This aurora was seen during the great solar storm of 1859. The southern lights may have been seen as far north as Singapore, eight degrees south of the equator.

When are they visible?

This is an important question! Sometimes, people who don't live in the range of auroras will travel long distances to see them. There is a whole tourist industry devoted to aurora-spotting!

The northern lights are visible for more days each year the further north you go. The same applies to the southern lights. So, if you live in Nunavut, you could see them between October and April each year. If you're lucky enough to go to Antarctica, you could see them between March and September, during the Antarctic winter.

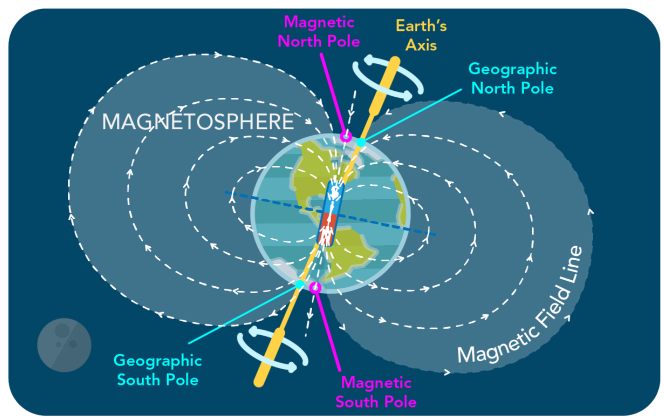
How do they happen?

Like other magnets, Earth generates a **magnetic field**. The field extends from the Earth's core, out into space, and back again. It starts in the southern part of the planet and ends in the northern part of the planet.

The path of the field is often represented in illustrations, like the one below, as **magnetic field lines**. These form a bubble around the globe with deep dimples at the north and south poles.

The region influenced by the magnetic field around the Earth is what scientists call the **magnetosphere**.

EARTH'S MAGNETIC FIELD

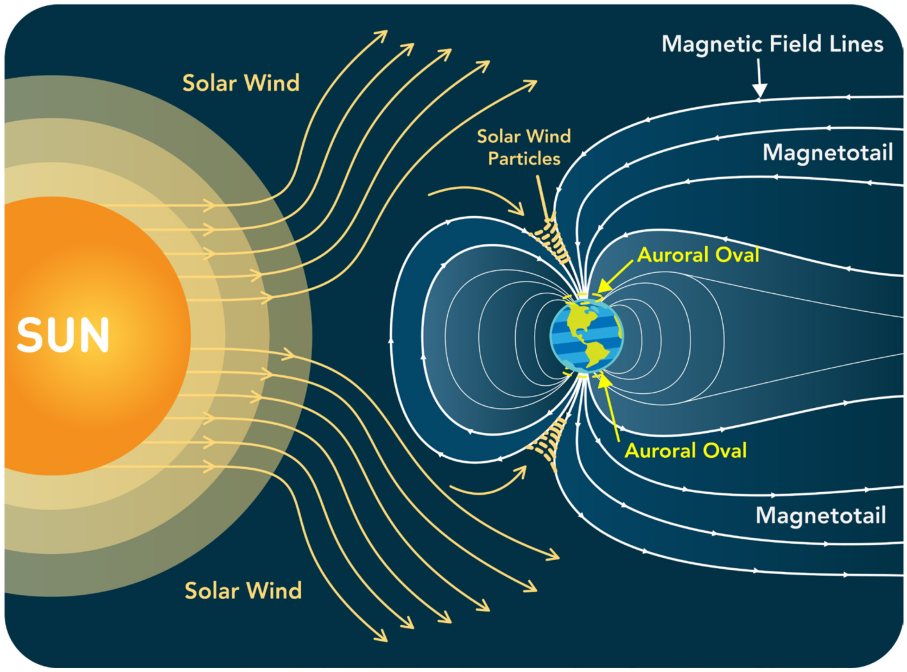


Earth's magnetic field (Let's Talk Science using an image by VectorMine via Getty Images).

The shape of the magnetosphere steers solar particles towards the poles. Here, they form **auroral ovals**. These are bands of aurora activity. But auroral ovals are not always the same shape or size. Why is this?

The solar particles travel to Earth in **solar wind**. These winds push on the magnetosphere on the side of the Earth that faces the Sun. This forms a **magnetotail** on the night side. The stronger the solar wind, the more an aurora oval will stretch.

Solar Wind and Magnetosphere



How solar wind interacts with the magnetosphere (Let's Talk Science using an image by VectorMine via Getty Images).

Did you know?
Solar winds cause the particles to hit Earth's upper atmosphere at more than 72 million kilometres per hour.

Sometimes, the solar winds can be so strong that they make the magnetic field lines stretch and snap back on the other side of the globe. Like snapping an elastic band, this sends lots of energy to Earth's poles. This phenomenon, called **magnetic reconnection**, creates some spectacular auroras! **Solar Storms** can also cause bursts of auroras.

Solar winds and solar storms cause auroras by starting geomagnetic storms and substorms in Earth's magnetosphere. Scientists can predict these storms like they predict the weather on Earth. They measure disturbances in the magnetosphere using a scale they call the **planetary K index**, or **Kp**. The Kp scale goes from 0 to 9. A forecast below 5 Kp means auroras are not very likely. But a forecast of 8 or 9 Kp could mean a spectacular light show is on the way.

Do auroras make a sound?

In the **Sámi** language, one of the names for aurora borealis translates as "the light you can hear." The Sámi language is spoken in Indigenous communities in northern parts of Finland, Sweden, Norway and Russia.

In the 1930s, people in northern Scotland wrote to a local newspaper to report that the aurora made a sound like rusting silk. Many other people and communities have reported that an aurora makes sizzling or popping noises.

Scientists were skeptical about these reports for a long time. Because auroras happen so far above Earth, people on the ground should not be able to hear them. But in 2001, scientists recorded sounds during auroras in eastern Finland. They are still working to record and understand auroral sounds, but they think that they are caused by changes in **static electricity** in our atmosphere. These changes happen because of the disturbances in Earth's magnetosphere during auroras.

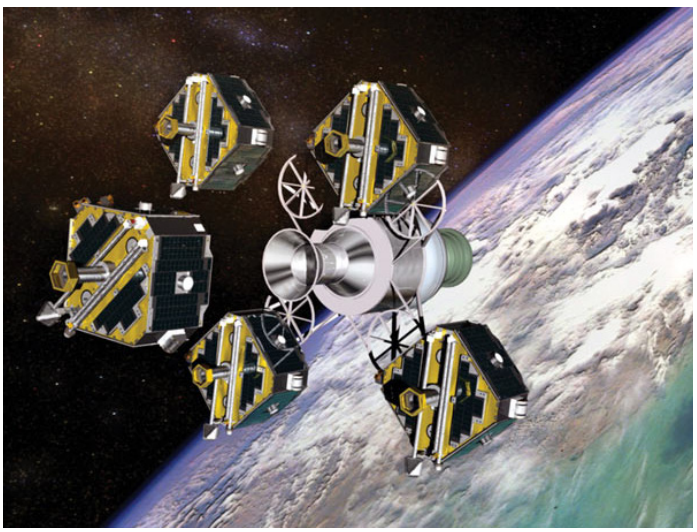
Auroras: A Source of Fascination

Humans have been fascinated by auroras for as long as we've been able to see them. So it's not surprising that people around the world have been sharing information about them for a long time, in many different ways.

One of the first written accounts of the auroras was by Assyrian astronomers around 679-655 B.C. But it wasn't until 1619 that the lights got the name aurora borealis. Italian astronomer Galileo Galilei named them after Aurora, goddess of dawn, and Boreas, god of the north wind in Greco-Roman mythology. Norwegian scientist Kristian Birkeland was the first person to theorize that auroras were caused by solar storms.

Scientists still don't know everything about auroras, even though they have studied Earth's magnetic field and solar winds. They still don't know exactly where the colourful reactions happen. One way they thought they could find out was through the use of satellites.

In 2007, NASA launched five small satellites as part of the THEMIS mission. Each satellite carried an array of electric, magnetic, and particle detectors. Every four days they lined up along Earth's magnetic tail and tracked disturbances in the magnetosphere. Scientists compared this information to millions of photographs taken at the same time from observatories on the ground. Some of the satellites are still up there, collecting more information. Auroras certainly are a spectacular light show!



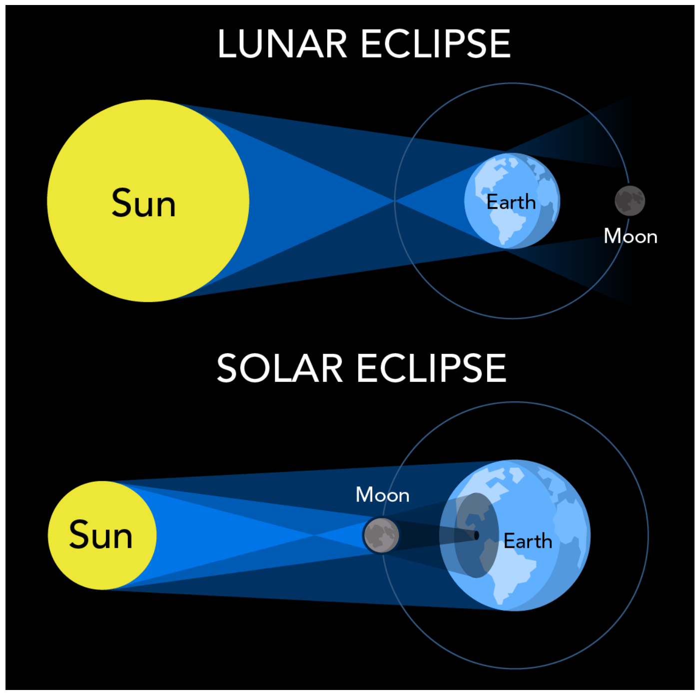
Artist's drawing of THEMIS satellites (Source: Public domain image by NASA).

Get Ready for a Total Solar Eclipse!

Do you know why people in Canada will remember April 8, 2024? It is because many of them will be able to experience a rare total solar eclipse.

What is a solar eclipse?

There are two types of eclipses. Lunar eclipses and solar eclipses. During a **lunar eclipse** the Earth casts a shadow on the Moon. During a **solar eclipse** the Moon casts a shadow on the Earth. This happens when the Moon passes between the Sun and Earth. As it does so, it blocks some or all the Sun's rays. Scientists call the area of darkness caused by an eclipse the path of the eclipse.



Solar versus lunar eclipse (Source: in8finity via Getty Images).

Did you know that there are different types of solar eclipses? Let's learn more about each.

Types of Solar Eclipses

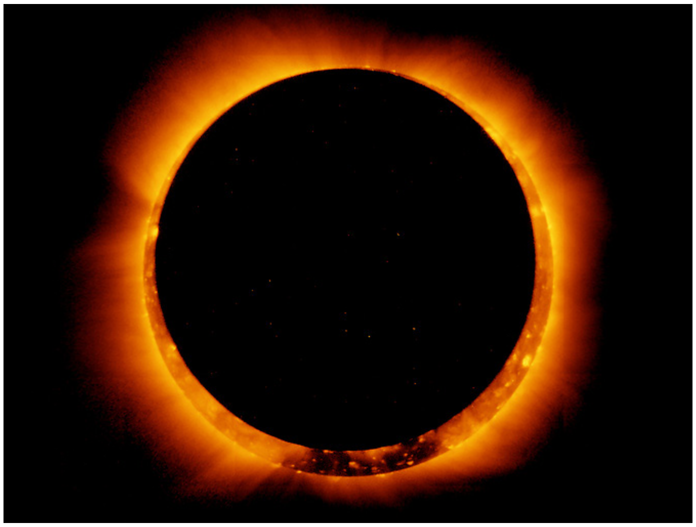
Total Solar Eclipse

A total solar eclipse happens when the Moon completely covers and blocks the light from the Sun. In the path of a total solar eclipse, the Earth experiences a short period of darkness, like at night. If the sky is clear, people in this path will be able to see the Sun's **corona**. This part of the Sun is not usually visible because it is outshone by the Sun's light.

Annular Solar Eclipse

An annular solar eclipse is like a total solar eclipse, but it occurs when the Moon is farther from Earth. In this case, the Moon does not completely cover the Sun. Instead, the Moon looks like a dark circle on top of a larger, bright circle. This forms what looks like a ring around the Moon.

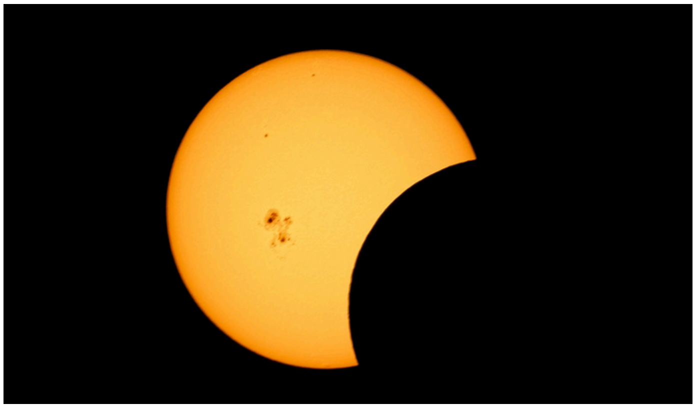
> Did you know?
> People sometimes refer to an annular eclipse as a "ring of fire".



Annular solar eclipse taken by a solar optical telescope (Source: NASA).

Partial Solar Eclipse

A partial solar eclipse happens when the Moon, Sun and Earth are not quite lined up. The Moon covers only part of the Sun in this case. This makes the Sun appear to have a crescent shape.



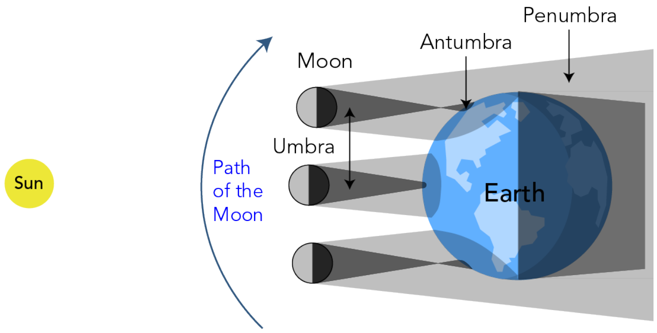
Partial solar eclipse seen from New Mexico, USA (Source: potenciaverde via Getty Images).

During total or annular solar eclipses, people off the path of the eclipse see a partial solar eclipse.

Hybrid Solar Eclipse

Sometimes an eclipse shifts between each type. Astronomers call this a **hybrid solar eclipse**. The type of eclipse you see depends on where you are in its path. Hybrid eclipses happen because of the shape of the Earth and the relative location of the Moon to the Earth.

If you are in the path of the Moon's **umbra**, you see a total eclipse. If you are in the path of the **antumbra**, you see an annular eclipse. If you are in the path of the **penumbra,** you see a partial eclipse.



Path of the Moon during a hybrid solar eclipse (Let's Talk Science based on an image by Vallastro [CC BY-SA 4.0] via Wikimedia Commons).

> Did you know?
> Solar eclipses only take place during a new Moon phase.

Frequency of Solar Eclipses

The Earth experiences two to five solar eclipses each year. Total solar eclipses happen about every 18 months.

You might wonder why solar eclipses are so rare since the Moon often passes between the Sun and the Earth. Eclipses only happen once in a while because the Moon does not **orbit** in the same plane (flat surface) as the Sun and the Earth.

The Moon's orbit around Earth is tilted about 5 degrees compared to Earth's orbit around the Sun. Nodes are the points where the two planes cross over. There are two nodes where the Moon's orbit crosses the Earth's orbit. Solar eclipses only happen when the Moon is close to one of the two nodes.

Did you know?
The same location on Earth only experiences a total solar eclipse every 400 years.

After the total solar eclipse in April 2024 solar eclipse, the next solar eclipse visible in Canada will be a partial solar eclipse in March 2025. The next total solar eclipse in Canada will be in August 2044.

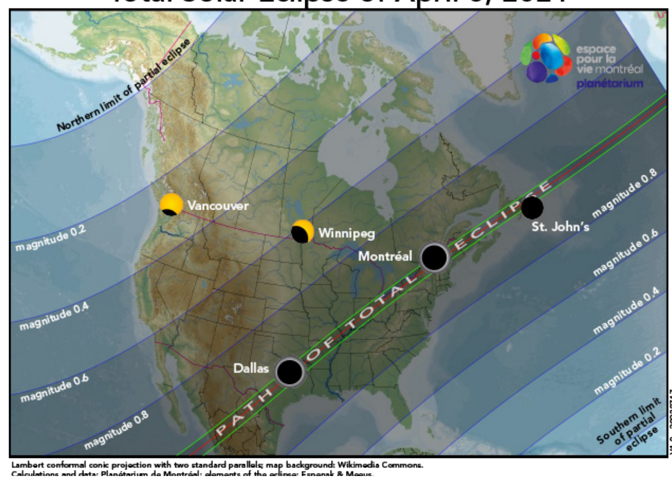
Paths of Solar Eclipses

Solar eclipses do not always follow the same path. Astronomers see tightly curved paths over the north and south poles. They see paths that are less steeply curved near the equator.

Did you know?
Solar eclipses follow a pattern known as a Saros. The same path repeats every 18 years, 11 days and eight hours, but over a different location on Earth.

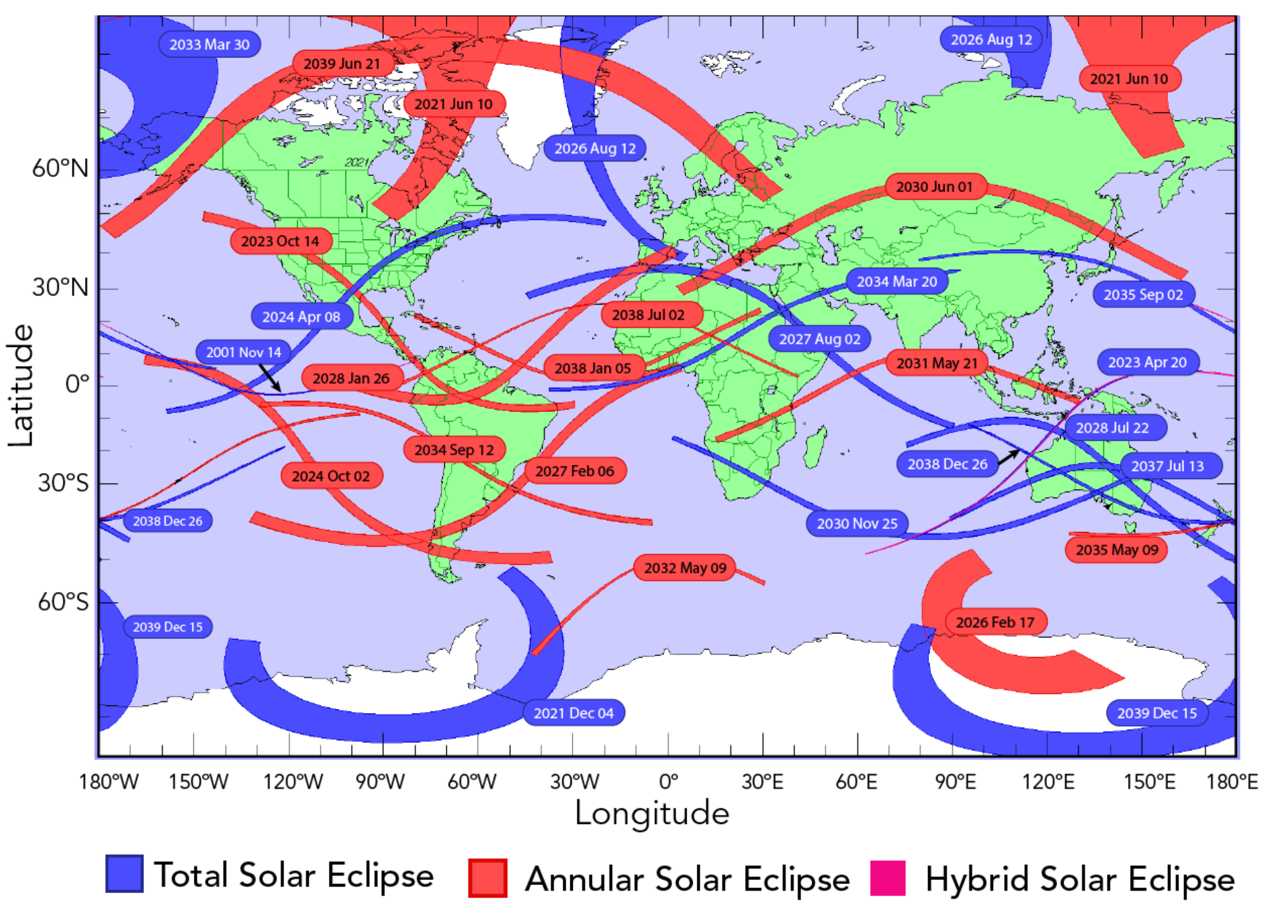
The path of the 2024 total eclipse will travel from the southwest to the northeast part of North America. You can see exactly which parts of Canada will be directly on the path using the map below.

Total Solar Eclipse of April 8, 2024



Map showing the visibility of the April 8, 2024 Solar Eclipse in North America. Lambert conformal conic projection with two standard parallels; map background: Wikimedia Commons. Calculations and data: Planétarium de Montréal; elements of the eclipse: Espenak & Meeus. (Source: Montréal Space for Life used with permission).

Total and Annular Solar Eclipse Paths: 2021-2040

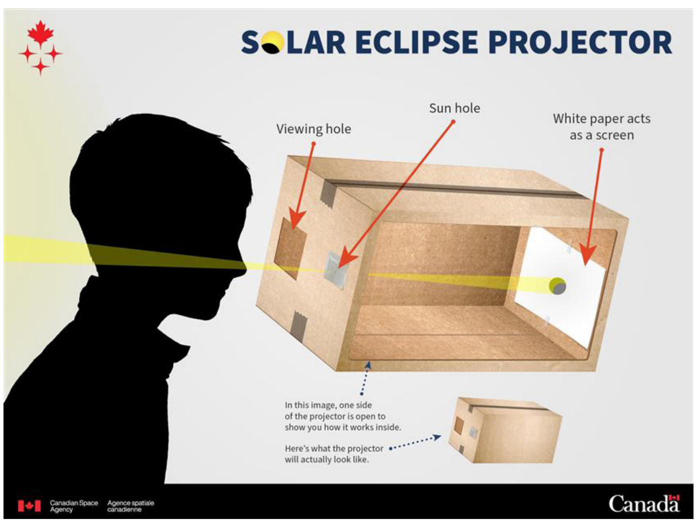


Predicted paths of total and annular solar eclipses from 2021 to 2040 (Source: Let's Talk Science adapted from a Public domain image courtesy of Fred Espenak, NASA/Goddard Space Flight Center via Wikimedia Commons).

Solar Eclipse Viewing

Solar eclipses are pretty cool to watch, but you do need to be careful. Here are some tips for safe solar eclipse atching.

- Make sure to always wear approved eclipse glasses when looking at the Sun.
- NEVER look at the Sun using regular sunglasses or through black garbage bags. These do not filter the infrared radiation from the Sun, which can do permanent damage to your eyes.
- NEVER look at the Sun through binoculars or a telescope unless you are using a solar filter with them.
- Safer still is watching an eclipse using a pinhole projector.



Solar eclipse projector (Source: Canadian Space Agency).

Did you know?
It takes several hours for the Moon to pass in front of the Sun, but the time when the Sun is totally eclipsed, called the totality, only lasts a maximum of seven minutes and 32 seconds.

How can you adapt communications to overcome interference?

Consider using the Design & Build Process with this challenge.

This activity will help build skills related to the Identify the Problem, Generate Ideas, Plan, Create, Test and Evaluate phases of this process.

Materials:

- Paper and writing tools (optional)
- Recycled materials (optional)
- A device that can play music loudly or a fan (optional)

What to do!

Gather a group of two or three people. Imagine that a **geomagnetic storm** is making global communications cut in and out. How can you get a message to a partner even if it is interrupted part way through?

1. **Identify the Problem** – The person sending and the person receiving the message should be at least five metres apart. Their communication method cannot involve any technological devices. There will be an “interrupter” between the sender and receiver. This can be a person, or something loud. Maybe a device playing music or a fan on its highest setting - get creative!
2. **Generate Ideas** – Brainstorm as many ways to communicate over a distance as you can. You might need more materials for some of the ways. For others, you might not need anything except yourselves. But remember, no electronics or technology allowed!
3. **Plan** – Pick one or two of your favourite ideas. Think about how they will work. Gather any materials you might need.
4. **Create** – Build a prototype if you need one to carry out your idea. Come up with a test message. It should be no longer than a few sentences.

5. **Test** – The sender and receiver test their communication method. The interrupter tries to interrupt the message. The interrupter is not allowed within one metre of a communicator. Also, they cannot break any physical part of the communication method, but they can touch it. The sender and receiver may need to adapt their communication method to the ways the interrupter is interfering. Try switching roles and repeating the test.
6. **Evaluate** – How well did your method work? What were some of the strengths and weaknesses of your method? Would your method work in different situations?

What's happening?

The 'interrupter' is acting like a geomagnetic storm. The increased electromagnetic activity during these storms can interfere with radio waves. This interference can disrupt long-distance communication.

Why does it matter?

Communication is important to all aspects of life. Building resilient communication systems minimizes the effects of events like geomagnetic storms and extreme weather.

Investigate further!

- How reliable is your method? What adaptations would make it more reliable?
- Could you send a longer message using your method? Why or why not?
- How accurate is your method? Could it be made more accurate?
- What if your message needs to be kept private from others? Would your method do this?

Anastasiia Prysyazhnyuk

Science and Innovation Lead, Health Beyond Initiative
Canadian Space Agency

I was born in Chernivtsi, Ukraine. I now live in Toronto, Ontario. I completed my BSc in Human Biology: Health and Disease at the University of Toronto and a MHSc in Health Informatics at Ontario Tech University.

What I do at work

My workday varies, depending on the status of our activities. Mostly, it involves a lot of teamwork with other scientists and engineers. These people can be located in Canada or abroad. We work together to identify the healthcare needs for future space missions. We also explore the technologies that are needed to support them.

This work requires various STEM skills, so that all aspects of healthcare problems are considered. My team and I also organize events that bring together people from academic circles, industry and government. The goal is to foster communication and collaboration between these groups. In this way, we will have a strong community of Canadian innovators.

My career path

In high school, I enjoyed science and math. I always had a strong desire to help people. I was genuinely curious about health and the various factors that influence it. This led me to pursue a Bachelor of Science Degree with specialization in Human Biology.

After I finished my undergraduate studies, I started working at the healthcare facility. Later I decided to continue with a graduate degree. I enrolled in a Master of Health Sciences degree at Ontario Tech University. Here, my path crossed with the Russian pioneer of space cardiology. This introduced me to the field of space medicine and I never looked back.

I learned that many of the health problems in space are similar to what is faced by some populations on Earth. This included caring for babies and the need for first responders. I was fortunate to have a supervisor who conducted research in these populations. Luckily, I was able to be a part of this research too. After my graduate studies, I completed an internship at the Canadian Space Agency. This led me to the position I am in today.

I am motivated by

I am motivated by the novelty and the limitless potential of possibilities that exist. It's the passion and excitement of my co-workers that makes this work so motivating. The variety of projects supports continuous learning from the many experts in the field. It is such a rewarding feeling when things fall into places and complete a puzzle. It’s great when we solve a healthcare challenge! The solutions developed for space healthcare challenges also apply here on Earth. As a restul, my work has a huge impact.

How I affect peoples' lives

My work is important to ensure that humans can continue to explore the universe safely. It also helps to solve healthcare challenges here on Earth. For example, to help people living in rural and/or remote territories, where access to healthcare is limited.

My advice to others

Dare to dream big! Don't let the failures define you or your future. You can achieve anything you set your mind to.

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